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MJ Mendell[1*], WJ Fisk[2], MR Petersen[1], CJ Hines[1], M Dong[2],
D Faulkner[2], JA Deddens[1], AM Ruder[1], D Sullivan[2], MF Boeniger[1]

[1]National Institute for Occupational Safety and Health
Cincinnati, OH, USA

[2]Environmental Energy Techologies Division
Indoor Environment Department
Lawrence Berkeley National Laboratory
Berkeley, CA

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[1]*National Institute for Occupational Safety and Health, Cincinnati, OH, USA*

[2]*Lawrence Berkeley National Laboratory, Berkeley, CA, USA*

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Reprint Requests to:

Mark J. Mendell, Ph.D.

Lawrence Berkeley National Laboratory

1 Cyclotron Road, MS 90-3058

Berkeley, CA 94720

PH: 510-486-5762

FX: 510-486-6658

e-m: mjmendell@lbl.gov

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ABSTRACT

Background

We studied the effects of removing small airborne particles in an office building without unusual contaminant sources or occupant complaints.

Methods

We conducted a double-blind crossover study of enhanced particle filtration in an office building in the Midwest U.S. in 1993. We replaced standard particle filters, in separate ventilation systems on two floors, with highly efficient filters, on alternate floors weekly over four weeks. Repeated-measures models were used to analyze data from weekly worker questionnaires and multiple environmental measurements.

Results

Bioaerosol concentrations were low. Enhanced filtration reduced concentrations of the smallest airborne particles by 94%. This reduction was not associated with reduced symptoms among the 396 respondents, but three performance-related mental states improved; for example, the confusion scale decreased (-3.7%; 95% confidence limits (CL) = -6.5, -0.9). Most environmental dissatisfaction variables also improved; *eg*, "stuffy" air, -5.3% (95% CL = -10.3, -0.4). Cooler temperatures within the recommended comfort range were associated with remarkably large improvement in most outcomes; for example, per 1ºC decrease, chest tightness decreased -23.4% (95% CL = -38.1, -8.7).

Conclusions

Benefits of enhanced filtration require assessment in buildings with higher particulate contaminant levels, in studies controlling for temperature effects. Benefits from lower indoor

temperatures need confirmation.

Key Words: indoor air pollutants, particles, symptoms, intervention studies, air filtration, temperature

Indoor work environments such as offices have traditionally been considered free of harmful exposures. In the last two decades, however, indoor workers have complained increasingly of acute symptoms and discomfort. Reported symptoms have included eye, nose, and throat irritation, headache and fatigue, dry or irritated skin, and breathing problems. This group of complaints, sometimes called sick building syndrome symptoms, will be referred to here as building-related symptoms.

Available scientific evidence suggests that building-related symptoms are associated with a combination of chemical, microbiological, physical, and psychosocial exposures, and that current exposure assessment strategies do not adequately characterize some of these.[1] A number of studies have now documented objectively measurable health effects to be associated with subjectively reported building-related symptoms or with changes in indoor environments.[2,3,4]

Identified risk factors for building-related symptoms include air conditioning or humidification systems, carpets, lower outdoor air ventilation rates, higher levels of Gram-negative bacterial endotoxin, higher temperatures, and very low relative humidities.[1,5,6] Evidence suggests that increased levels of some indoor contaminants increase occupant symptoms and environmental dissatisfaction.[7,8] Other evidence suggests that thermal conditions, possibly in conjunction with indoor pollutants, influence perceived air quality.[9,10,11]

Most field studies in this area have been cross-sectional and observational.[1] These have identified risk factors and generated hypotheses but have associated few measured exposures with building-related symptoms. Experimental studies,[1,2,12,13] by changing one factor at a time, can better isolate direct effects.

This study was suggested by observations that particulate contaminants or their sources are associated with acute occupant symptoms in indoor office and residential environments[6,7,14,15,16,17] and that irritant contaminants may increase sensations of stuffy, dry air.[7,18] The goal of this study was to assess benefits of a generalizable intervention, rather than a building-specific mitigation.

Methods

Study methods, described elsewhere,[19] are briefly summarized here. A double-blind, multiple crossover intervention design was used in summer 1996 to assess benefits for symptoms and comfort of the enhanced removal of small airborne indoor particles through improved central filtration. The study protocol was granted exemption by the Institutional Review Board of the National Institute for Occupational Safety and Health. The experimental study spaces were two separate floors (floors 2 and 4, with 185 and 307 workers) of mostly "open plan" partitioned office space within a large office building (1900 m^2). The building, located in the midwestern United States, was occupied by office workers from a government agency. Building management had reported sporadic occupant complaints about comfort, but not about symptoms. Smoking was not permitted within the building.

Intervention methods

The study was performed in a hot-summer region so ventilation systems would supply minimum outdoor air throughout the study. Stable, low outdoor air ventilation rates were considered optimal conditions for studying the benefits of enhanced filtration.

The study began with installation of clean conventional filters in the ventilation systems of both study floors. Filter location was in the air stream of mixed outside and recirculated air. After two weeks of baseline measurements, highly efficient particle filters were installed in the ventilation system of floor 4 during the weekend and left installed for one week. The next weekend, conventional filters were reinstalled on floor 4 and the enhanced filters installed in the ventilation system of floor 2. This pattern was repeated in intervention weeks three and four.

The estimated efficiency of the normal filters was 3%, 15%, 40%, and 80% for particles with diameters of 0.3, 0.85, 1.5, and 3 µm.[20] The high efficiency filters had an efficiency rating of 95% at 0.3 µm with higher efficiencies for both smaller and larger particles.[21] Building occupants and staff were blind to both the schedule and type of intervention (except contract staff maintaining the ventilation system, who agreed not to disclose this information).

Questionnaire methods

An initial self-completed background questionnaire for workers collected informed consent, demographic data, and information on location, health history, job, and job stressors. Shorter weekly questionnaires assessed a variety of outcomes, including:

- severity that day of eight symptoms (seven previously associated with indoor air quality and one set of "control" symptoms assumed unrelated to indoor air quality -- sore back, shoulders, or neck).
- performance-related mental states, hypothesized to be related to indoor air quality. Two of these, mental confusion and fatigue, were assessed by five-question mood sub-scales from the Neurobehavioral Evaluation System,[22] a set of computerized neurobehavioral tests, administered here with paper and pencil. The third used a single question about self-assessed productivity.
- aspects of environmental dissatisfaction, including three hypothesized to be potentially affected by particulate contamination (stuffy, dusty, too dry)
- perceived environmental changes, to assess blinding of the intervention.

The use of a visual analog scale (VAS) for symptoms follows Wyon,[2] although symptoms were assessed here using rows of 26 circles to allow electronic scanning of responses. Pre-testing found similar within-person variability from this format and traditional VAS lines.[23] Questions on productivity-related mental states and on environmental dissatisfaction provided five response categories: “not at all,” “a little,” “moderately,” “quite a bit,” and “extremely.” Workers received questionnaires each Thursday morning, with instructions to complete them in the afternoon on Thursday or Friday. Each study week, all workers present Thursday or Friday were eligible. Study staff blinded to the intervention schedule handled questionnaires and interactions with workers.

Environmental measurements

Environmental measurements included temperature, humidity, carbon dioxide concentration, and effective outdoor air ventilation rate, all unaffected by the intervention and potentially requiring adjustment in analyses. Airborne contaminants potentially affected by the intervention, and therefore not adjusted in analyses, were also measured: concentrations of particles, endotoxin, ergosterol, and beta-1,3-glucans. Air temperature and humidity were measured and logged continuously at multiple locations on each floor. The humidity metric used was the humidity ratio (the mass of water vapor divided by the mass of dry air), which is independent of temperature. For both humidity and temperature, analyses used the time-weighted values in the space where each respondent worked, during the workday on which the questionnaire was completed. Details on environmental measurements are provided elsewhere.[19,24,25,26]

Data analysis

Intervention effectiveness was assessed with models containing terms for week, location, person, and intervention. We assumed that the levels of the response variables were equally spaced. Modeling was performed in SAS, version 6.12,[27] using, for each of 18 outcomes, a mixed linear model (PROC MIXED) with a random person effect, maximum likelihood estimation, and assumption of a compound symmetric covariance structure. These models produced unadjusted estimates and, after potential inclusion of other covariates (temperature, humidity ratio, carbon dioxide, ventilation rate, and job stress), adjusted estimates. Analyses assumed a same-week filtration effect with no residual effect during the following week. Estimated standard errors were used to calculate 95% confidence limits (CLs) (or confidence intervals [CIs]), without adjustment for calculation of multiple estimates. Adjusted effect estimates were calculated for each outcome as the absolute change and as the percentage of the mean, with 95% CLs (or CIs).

Results

Of 457 initially eligible respondents among 492 workers on the two floors, 396 (135 on floor 2, 261 on floor 4) returned the background questionnaire and consent form, for an 81% initial response rate. During the four crossover weeks, response rates were substantially lower, averaging 63%, with usable questionnaires averaging 58%.

Table 1 shows demographic characteristics among initial respondents. Differences between the respondents on the two floors were greatest for job, education, and military status; however, within-person data analyses made these differences unlikely to affect the findings. Those who completed at least two questionnaires during the intervention (Table 1) differed demographically only slightly from the entire group completing the initial questionnaire. As the latter included 81% of eligible workers on the study floors, participants in the intervention were reasonably representative of all eligible workers. Responses to questions designed to assess blinding of the intervention showed that participants were not aware of the specific times or nature of the enhanced filtration intervention. Almost all perceived changes reported relative to the previous week concerned temperature.

Initial symptom prevalences were close to average for U.S. office buildings; *eg*, initial prevalence of weekly work-related eye irritation was 20% in this population compared to 17% in representative U.S. office buildings surveyed by the U.S. EPA (fax communication, Howard L. Brightman, October 1998). Weekly average carbon dioxide concentrations in the study spaces (range 589-738 parts per million) were typical for US office buildings.[19] Ventilation rates were typical as well (range 9.0-16.2 liters per second per person, estimated using the effective outside air ventilation rates for Thursday and Friday of each week, and average occupancies of 165 and 280 for floors 2 and 4, respectively). For each floor, outdoor air ventilation rate was nearly constant throughout the study (Table 2), providing outdoor air at the minimum settings. Airflow measurements confirmed that, consistent with engineering predictions, the enhanced filtration produced no measurable reduction of ventilation airflow.

Table 2 summarizes weekly environmental parameters by floor. Indoor temperatures (22.2-25.6ºC) and relative humidities (42-58%) were mostly within the accepted summer comfort limits of 22.8-26.1ºC at 50% relative humidity.[28] As previously reported, indoor air concentrations of the fungal indicators measured were mostly below detection limits; *ie,* for seven of eight ergosterol samples (the detectable value, 2.6×10^{-4} ng/m^3, was about 40% of the outdoor levels) and for 17 of 30 beta-1,3-glucan samples (the *maximum* indoor air concentration, 1.2 ng/m^3, was less than one-third of the median outdoor concentration). Air levels of endotoxin (an indicator of Gram-negative bacteria) were very low, with 23% of samples below the detection limit and a geometric mean of 0.24 endotoxin units/m^3.[24]

Enhanced filtration reduced airborne concentrations of 0.3-0.5 micron particles, the smallest we measured, by 94% (Table 2). Size-specific particle number concentrations were reduced by 84% for 0.5-0.7 μm, 72% for 0.7-1.0 μm, 55% for 1.0-2.0 μm, and 16% for >2.0 μm particles.[21] Benefits of high efficiency filtration over conventional filtration decreased as particle size increased (Table 2), presumably because of increasing efficiency of conventional filters with larger particles. Furthermore, there was no evidence that enhanced filtration reduced the already low air concentrations of endotoxin, as reported elsewhere.[24]

On each floor, the highest values for both symptom severities and environmental discomfort occurred during week 1, and most decreased substantially afterwards, even before the filtration intervention began in week 3 (data not shown).

Each outcome model contained identical covariates. Because ventilation during the study was nearly stable, related metrics (carbon dioxide concentrations and effective ventilation rates) were only weakly correlated with occupant outcomes and were not included in models. Indoor Two thermal parameters, indoor temperature and indoor humidity ratio, were strongly correlated with most outcomes and were included in all models.

Table 3 provides both unadjusted and multivariate-adjusted estimates from the models of changes in occupant outcomes associated with the intervention. As all reported outcomes are adverse, *negative* estimated changes represent improvements. Adjusted estimates were generally similar in magnitude to unadjusted, except that with adjustment fewer symptom outcomes showed improvement with enhanced filtration. Table 3 also shows multivariate-adjusted changes in outcomes associated with decreasing temperature.

Figure 1 shows adjusted estimates and 95% CIs for change in outcomes, as per cent of outcome means, associated with enhanced filtration and per 1ºC decrease in temperature. With enhanced filtration, no symptom showed strong evidence of change; all CIs were broad. Skin symptoms showed a potential worsening, with eye and throat symptoms showing lesser potential worsening. With enhanced filtration, 95% CIs for five of 17 outcomes (excluding the control outcome) excluded or nearly excluded the null, all with estimated improvements. Performance-related mental states all showed improvement (and relatively narrow CIs, which can be calculated from Table 3) —mental confusion scale, -3.7%; fatigue scale, -2.5%; and "less productive," -2.1%. The environmental dissatisfaction variables that most clearly improved with enhanced filtration were "too humid," -7.0%; "stuffy," -5.3%; and, to a lesser extent, both "too cold," -5.5% and "too warm," -3.5%.

Lower temperatures, even within the accepted summer comfort range, were strongly related to improvements in all adverse outcomes, including the control outcome, except two: "too cold" and "drafty" (Figure 1). For the 16 outcomes showing improvement, all 95% CIs excluded 0%. Each 1ºC decrease in temperature was related to a 19% decrease in severity of eye symptoms and to decreases in "stuffy" and "too warm" (19% and 25%) that greatly exceeded the related increases in "drafty" or "too cold" (2% and 3%).

Within the observed 42-50% range of relative humidity, an *increase* of 1×10^{-3} humidity ratio units (roughly equivalent to increased relative humidity of 6.7% within the observed range), was associated with at least small improvements in all outcomes except "too dry" and "too humid;" however, 95% CIs excluded 0% only for chest (-38.4%, 95% CL = -60.6, -16.3), throat (-19.1%, 95% CL = -37.4, -0.7), and fatigue symptoms (-14.7%, 95% CL = -27.5, -1.8). These were roughly comparable to the estimated benefits of *decreasing temperature* by 1.6, 1.4, and 0.9ºC, respectively, at constant humidity (data not shown).

Discussion

In this office building without known unusual sources of contamination or evident health complaints from occupants, enhanced removal of small particles from the indoor air was not associated with reduced symptoms. Still, the 94% reduction achieved here in 0.3-0.5 micron airborne particles and lesser reductions in larger particles were associated with small improvements in all performance-related mental states assessed and most measures of environmental dissatisfaction (including the improvement predicted for "stuffiness"). Chance, although perhaps explaining small improvements in many of these outcomes, does not provide a plausible explanation for the reductions observed in mental confusion, perceived environmental stuffiness, and perceived excess humidity (-4%, -5%, and -7%, respectively). These strong associations would not have been expected by chance among 18 outcomes, if there were no true relationship. The -2.5% improvement on the five-item fatigue scale suggests a small reduction in fatigue, despite the +0.6% worsening on the single-item fatigue symptom question.

Assessment of study validity

Design strategies used in this study should have increased validity relative to some other indoor environmental studies. The double-crossover intervention design used repeated measures and within-subject analyses to compare study groups with the same employer, within the same building, and with separate but identical ventilation systems. This design reduced potential bias from differences in stable environmental, job, and personal factors between the two groups.

Within-person analyses adjusted for weekly individual levels of work stress reduced potential bias from high (and changing) levels of worker stress related to impending layoffs. The double-blind condition, successfully maintained, prevented bias from suggestion effects among both participants and study staff. Three elements of the study protected against bias from the previously observed weekly decrease in symptoms on repeated symptom questionnaires:[12,29,30] delaying the crossover intervention until the third study week when outcome reporting was more stable, using a simultaneous comparison group without the intervention, and adjusting for week of study in analyses. The study assessed current outcomes to reduce recall bias, measured and analyzed these as continuous outcomes to increase sensitivity relative to matched analyses of dichotomous outcomes, and compared outcome data from the same time period as the environmental measurements.

We measured temperature, humidity, and ventilation rate to allow adjustment in analysis, as these cannot be precisely controlled in field studies and have been previously associated with symptoms and discomfort in occupants.[1,31] Residual confounding by temperature could not have produced the benefits found here from enhanced filtration, as average temperatures for the two filtration conditions were essentially identical (Table 2). The ventilation rates were sufficiently stable to require no statistical adjustment.

A number of inherent limitations may have caused error in the findings of this study. The modest sample size (230 questionnaires per week) and low baseline levels of indoor contaminants produced an under-powered study. However, the within-person analyses and the representativeness of responders should have prevented bias from low weekly response rates. The use only of subjective self-reported outcome measures made detection of effects more difficult due to potentially increased misclassification. Comparing existing configurations of workers rather than groups of randomly selected individuals, unavoidable in this occupational setting, should not have caused bias, but may have caused slight overestimation of the precision of estimates. If any filtration effects on occupants had residual influence into the next week and the changed filtration condition, findings would be distorted; however, exploratory models assuming residual effects estimated generally greater immediate benefits from enhanced filtration on most outcomes.

Possible mechanisms for effects associated with enhanced filtration

Available information on the health effects of small particles, mostly concerning outdoor particles, suggest that higher concentrations of small particles influence acute symptoms, hospital admissions, and mortality rates.[32] These exposures, however, probably occur mostly indoors, where people spend 90% of their time, as a high proportion of small particles produced outdoors penetrate indoors. Efficient filtration would reduce exposures to small particles from either indoor or outdoor sources, including aerosols from outdoor combustion or photochemical processes and small fragments of pollens and other bioaerosols. This study did not assess impacts on chronic health effects such as reduced lung function or cardiovascular disease, which have been associated with higher concentrations of particles in outdoor air.[33]

The limited available evidence on health effects of airborne particles in indoor work environments, including observational studies[34,35] and experimental studies that *removed* airborne particles from indoor air,[2,21,36,37,38] has been mixed. Experimental exposures to office dust have found effects on skin and mucus membranes, headache, concentration difficulty, and confusion.[39,40] Particulate contaminants on indoor surfaces, which may be involved in indoor exposures, have been associated with increased occupant symptoms in previous observational studies,[15,41,42] although findings from experimental studies that reduced surface contaminants have been mixed.[29,43,44,45] Residential studies have extensively documented adverse health effects of airborne particles and benefits from removal (mostly among allergic or asthmatic individuals);[46] however, exposures to dust mites, pet dander, and fungi may be substantially larger in homes.

Microbiologic measurement results here provided no evidence for important exposures to fungal spores or spore fragments from indoor sources (as assessed by glucans and ergosterol) and did not suggest that filtration reduced the already low endotoxin exposures, which may be associated primarily with larger particles.[47] Furthermore, high efficiency filtration, relative to conventional filtration, would have only modestly reduced exposures (by less than 16%) to large particles such as fungal spores, whole bacteria, pollen grains, and material from dust mites.

Possible mechanisms for effects associated with temperature and humidity

For each 1ºC decrease within the 22.1-25.6ºC range observed, adverse outcomes decreased between 4% and 25% of their mean values. These findings suggest substantial occupant benefits from temperatures at the cooler end of the accepted summer thermal comfort range in air-conditioned buildings. Previously reported studies have found similar relationships of temperature with symptoms,[2,4,13,14] environmental dissatisfaction,[9,48] or both.[49,50,51] Others, often with less coincident measurements of environment and outcomes, have not seen these relationships.[52] At lower temperatures, the substantial reductions found here in discomfort from excess warmth, stuffiness, humidity, dryness, and dustiness were accompanied by much smaller related increases in discomfort from cold and draft. (One previous study found that average occupant comfort improved continually as temperature fell to 22ºC, and only below 22ºC did the proportion feeling too cool begin to rise.[48])

Various mechanisms may explain such broad effects of temperature: a reduction of air temperature reducing VOC-related symptoms (Mølhave et al.[49]); a temperature- and humidity-related perceptual "illusion that cooler and drier air is somehow freer of contaminants" (Berglund and Cain[9]); or the production by higher temperature of a sensation of dryness and stuffiness through reduced cooling of mucous membranes (Fang et al.[10]). The latter has some empirical support.[53]

Findings here that changing humidity was not associated with perception of dryness or moisture, although counter-intuitive, have been reported by numerous other researchers (*eg,* Sundell[18]). While many previous experimental studies have found increasing relative humidity to be associated with decreasing acceptability of air,[9,10,53,54] such data cannot be directly compared to findings in this study, which did not assess acceptability of air. By Fang's hypothesis,[10] increased humidity ratio should increase perceived dryness and stuffiness by decreasing evaporative cooling of mucus membranes. However, increased humidity ratio here was associated with no change in perceived dryness and a small *decrease* in stuffiness.

The small decreases in symptoms found here with increased humidity ratio were most convincing for throat, chest, and fatigue symptoms. Previous experimental studies have also found decreased symptoms with moderate increases in relative humidity.[2,55,56] Previous cross-sectional studies finding no association between humidity and symptoms (reviewed elsewhere[1]) tend to have substantial design limitations, such as a lack of correspondence between humidity measurements and periods of symptom recall. Associations of higher humidities with decreased symptoms would not in themselves justify use of active humidification in indoor environments, because of the decreased acceptability of air associated with increased humidity,[9,10,53,54] and more importantly, the documented risk of respiratory disease and symptoms associated with humidification systems.[57,58]

Future implications

This study demonstrates that air filtration can be used to assess the effects of small particles on occupants in an office building by temporarily decreasing concentrations of these particles twenty-fold. This study further demonstrates that controlling in analyses for the strong effects of temperature on reported acute outcomes is critically important in assessing accurately the effects of non-temperature changes. Cross-sectional or experimental studies without such control may erroneously attribute effects of temperature to other factors. In this study, mean temperatures during the four intervention weeks were identical for conditions of enhanced and of regular filtration (23.5ºC). Chance differences of even 0.5ºC, however, would have produced an almost 10% difference in eye symptoms which, unless corrected by adjustment, would have either hidden or tripled the estimated 4% reduction associated with enhanced filtration.

Findings here are consistent with slight benefits -- improved productivity-related mental states and reduced environmental dissatisfaction -- from decreased concentrations of small airborne particles in a building without evident contamination. Potential benefits even of the small size found in this study justify continued research, due to the potentially large aggregate benefits for millions of indoor workers. It is uncertain how the performance-related mental states assessed in this study relate to actual performance, but the potential economic gain in performance among occupants may exceed the cost of enhanced filtration more than eight-fold.[59] Similarly, the overall benefits of relatively cooler indoor temperatures, for symptoms, thermal comfort, and performance-related mental states, may be large. Net benefits found for higher moderate humidities are more uncertain. Clarification of all these relationships will require studies with larger sample size, better-controlled temperature, and possibly higher levels of particles and lower ventilation rates.

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Table 1. Demographic description of office workers participating in a double-blind crossover study of enhanced particle filtration in an office building, 1996

Variable	Answering initial questionnaire			Answering at least two weekly questionnaires during intervention
	Floor 2 %	Floor 4 %	Total %	Total %
female	67	56	60	57
age				
under 40	27	30	29	28
40-49	47	51	50	51
50+	26	19	21	21
race				
White	55	64	61	67
Black	34	22	26	23
other	11	14	13	10
job				

manager/supervisor	20	28	25	28
military personnel clerk	38	61	53	48
secretary/clerical	20	4.8	9.9	10
other	22	6.8	12	14
education				
less than college degree	69	60	63	61
college graduate	12	28	23	23
graduate degree	19	11	14	15
military status				
military	16	51	39	42
job stress*				
not at all/slightly	53	46	49	52
moderately/very	47	54	51	48
number of respondents (maximum; differs for each variable due to differing non-response)	135	261	396	308

* workers had recently been informed that half of those in the building would be laid off or

transferred

Table 2. Environmental parameters by week and floor in a double-blind crossover study of enhanced particle filtration in an office building, 1996

	Baseline				Intervention							
	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
Floor:	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**
Filtration:[*]	CF	CF	CF	CF	CF	**EF**	**EF**	CF	CF	**EF**	**EF**	CF
Environmental Parameters												
temperature (ºC)[†]	24.3	24.0	23.5	23.5	23.5	23.4	23.4	23.3	23.8	24.0	23.6	23.7
relative humidity	48.3	54.2	48.5	52.5	48.2	55.4	50.1	54.9	48.0	53.3	46.7	53.2
humidity ratio $\times 10^3$[†,‡]	9.4	10.0	8.9	9.4	9.0	9.7	9.2	9.8	9.1	10.0	8.8	9.7
carbon dioxide (ppm[§])	679	644	709	651	685	649	734	667	688	654	696	653
ventilation rate (m^3/sec)[¶]	1.9	3.5	1.9	3.3	1.8	3.2	2.0	3.3	1.9	3.3	2.1	3.2
particles, 0.3-0.5 :m (10^2/L)	287	414	95	162	158	9	8	134	441	17	39	911
particles, >2.0 :m (10^2/L)	0.8	0.8	0.8	0.7	0.6	0.9	0.7	0.8	0.7	0.6	0.8	1.7

* CF = conventional filtration; **EF** = enhanced filtration

† time- and occupancy-weighted values

‡ the mass of water vapor divided by the mass of dry air (a dimensionless number)

§ ppm = parts per million

¶ effective outdoor air ventilation rate

Table 3. Estimated changes in occupant outcomes over six weeks: with experimentally enhanced filtration (unadjusted and multivariate adjusted) and with observed temperature decrease (multivariate adjusted),* in a double-blind crossover study of enhanced particle filtration in an office building, 1996

		Outcome Change with Enhanced Filtration			Outcome Change with Decreasing Temperature	
		Unadjusted	Adjusted*		Adjusted*	
Outcome	Outcome Mean†	Change‡	Change‡	95% Confidence Limits	Change per 1°C‡,§	95% Confidence Limits

Symptom Severity[¶]						
eyes: dry, itching, or irritated	5.8	+0.12	+0.24	*-0.38, +0.87*	-1.11	*-1.76, -0.47*
nose: stuffy or congested	6.6	-0.25	-0.09	*-0.75, +0.57*	-0.84	*-1.52, -0.15*
throat: dry or irritated	5.3	-0.06	+0.19	*-0.42, +0.80*	-0.70	*-1.34, -0.06*
chest tightness	3.5	-0.12	-0.07	*-0.54, +0.41*	-0.82	*-1.33, -0.30*
headache	5.7	-0.20	+0.001	*-0.67, +0.67*	-1.01	*-1.68, -0.34*
fatigue or tiredness	7.9	-0.18	+0.05	*-0.60, +0.70*	-1.29	*-1.95 -0.63*
skin: dry, itchy, or irritated	5.0	+0.27	+0.33	*-0.20, +0.86*	-0.58	*-1.16, -0.01*
sore back, shoulders, or neck[#]	6.8	+0.27	+0.17	*-0.48, +0.82*	-0.90	*-1.56, -0.24*

Performance-related mental states[**]						
mental confusion scale[††]	1.9	-0.07	-0.07	*-0.12, -0.02*	-0.15	*-0.21, -0.09*
fatigue scale[‡‡]	2.7	-0.05	-0.07	*-0.14, +0.01*	-0.21	*-0.29, -0.13*
"less productive"	3.7	-0.07	-0.08	*-0.16, +0.003*	-0.15	*-0.24, -0.07*
Environmental dissatisfaction[**]						
too warm	2.3	-0.08	-0.08	*-0.20, +0.04*	-0.57	*-0.59, -0.46*
stuffy	2.3	-0.14	-0.12	*-0.24, -0.01*	-0.44	*-0.54, -0.33*
too dry	2.0	+0.09	+0.06	*-0.05, +0.17*	-0.20	*-0.32, -0.08*
dusty	2.2	+0.06	+0.04	*-0.04, +0.13*	-0.21	*-0.30, -0.11*
too cold	1.6	-0.06	-0.09	*-0.19, +0.02*	+0.05	*-0.06, +0.15*
drafty	1.6	-0.04	-0.04	*-0.13, +0.04*	+0.03	*-0.06. +0.12*
too humid	1.8	-0.11	-0.13	*-0.24, -0.01*	-0.32	*-0.43, -0.22*

[*] adjusted estimates from a repeated measures multivariate ANOVA model; terms in model include week, location, person, intervention, and mean temperature

[†] mean for weeks 1-6

[‡] negative change indicates improvement; change calculated as mean with enhanced filtration minus mean with conventional filtration

[§] in the observed range between 22.2-25.6ºC

[¶] symptom scale: 0=none to 25=very severe

[#] control symptom

[**] mental states scale and environmental dissatisfaction scale: 1=not at all to 5=extremely

[††] summed scores for "mixed-up" and "confused" minus scores for "able to think clearly," "clear-headed," and "able to concentrate"

‡‡ summed scores for "exhausted" and "tired" minus scores for "lively," "energetic," and "full of pep"

FIGURE 1 LEGEND.

Changes in occupant outcomes, and 95% confidence limits, with (A.) experimentally enhanced filtration and with (B.) observed temperature decrease, in a double-blind crossover study of enhanced particle filtration in an office building, 1996. Estimated change as percent of outcome mean – the adjusted change from Table 3 divided by the outcome mean for weeks 1-6, multiplied by 100. Negative change indicates improvement. Estimates from repeated measures multivariate analysis of variance model with terms for week, location, person, filtration status, mean day-of-questionnaire temperature, mean day-of-questionnaire humidity ratio, and work stress. Observed temperature range from 22.2-25.6ºC.